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Robust determinants of companies' capacity to innovate: a Bayesian model averaging approach

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ABSTRACT
Robustness of innovation determinants is a crucial component for the company's capacity to innovate and is increasingly central to our understanding of country (national) innovation capacity. The large number of internal and external determinants therefore raises the question of finding/perceiving the robust determinants of companies' capacity to innovate. By using a Bayesian Model Averaging approach, the World Economic Forum's (WEF) Competitiveness dataset of 135 countries, 10 periods, and a total of 1.239 observations, has been analysed. From 62 explanatory determinants, 27 determinants were found to be significantly and robustly correlated with companies' capacity to innovate. Our results show that the large number of the previously suggested innovation determinants is not robust. A holistic approach that jointly considers the internal and external determinants of CCI is proposed. A central ingredient of this approach is direct public and private financial support for performing research and development.

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Introduction

How robust the innovation determinants are is fundamental for companies' capacity to innovate (CCI) and is increasingly central to our understanding of national innovation capacity. For example, R&D expenditures (public and private) have been identified as a critical determinant of innovativeness (Furman, Porter, and Stern 2002). Yet many other determinants have been found to be significantly or partially related to innovation performance. Researchers have been 'trying' combinations of potentially significant variables and thus have reported the results of their model. However, such 'data-mining' could lead to spurious inference (Sala-i-Martin, Doppelhofer, and Miller 2004). Rather, what the 'true' significance of the variables for CCI is can both be identified and determined by the robustness of the explanatory variables across different model specifications. The identified variables' robustness across models may therefore reflect how the organisations and countries can structure and prioritise explanatory determinants to support the companies' capacity to innovate. This raises the question: which explanatory variables are robust determinants of companies' capacity to innovate?

Through the historical development of the field of strategic management the answer was researched around two explanatory systems: internally, towards firm characteristics, or externally, towards industry structure and a competitive position in the industry (Hoskisson et al. 1999). In the external system, the national innovative capacity is the central point around which the research

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is performed. The national innovative capacity is 'the ability of a country – as both a political and economic entity – to produce and commercialize a flow of new-to-the-world technologies over the long term' (Furman, Porter, and Stern 2002). It aims to identify the factors enabling a country to innovate at the global frontier (Porter and Stern 2001). The focus is on determinants in a broader social and spatial structure (Feldman and Florida 1994) outside of the company. These determinants constitute the national innovative capacity building blocks: nation's common innovation infrastructure, the environment for innovation in a nation's industrial clusters, and the strength of linkages between these two' (Furman, Porter, and Stern 2002). The main goal is, based on identified general patterns in the national innovative capacity that support or inhibit the CCI (Vega-Jurado et al. 2008), to shape the national environment to be more conducive to innovation (Porter and Stern 2001). However, Penrose (1959) identified that there is something inherent in the very nature of the firm that both promotes its growth and limits its rate of growth. Wernerfelt (1984) distilled this to a proposal of a resource-based view (RBV) of the firm, and Barney (1991) formalised the RBV logic by proposing a tangible and comprehensive framework to identify the needed characteristics of the firm's resources in order to generate sustainable competitive advantages. The resource-based view is the central point around which the internal explanatory system is established. According to RBV, innovation is also a result of the strengthening of the organisation's core competences (Vega-Jurado et al. 2008), these being: strategic, market, technological, and organisational competences (Tidd 2000). Following this approach, researchers have evaluated a considerable number of organisational characteristics as possible determinants (Damanpour 1991; Vega-Jurado et al. 2008), e.g. leadership, R&D, creativity management and others (Prajogo and Ahmed 2006).

Both explanatory systems have made a significant contribution to the understanding of the enabling factors of companies' capacity to innovate. However, calls have been made in the literature for a more integral understanding of the factors that influence the CCI and inclusion of both internal and external determinants in the analysis of which explanatory variables are robust determinants of companies' capacity to innovate (Damanpour 1991). This is also in line with the suggestions that explanations of the complex relationships in the new competitive landscape should be balanced between between internal and external explanations. This is shown by Crossan and Apaydin (2010, Appendix B), who through a systematic review of literature have demonstrated that organisational innovation is influenced by external and internal determinants. However, there is lack of exploration in innovation research that has undertaken this challenge of measuring the significance of internal and external determinants of companies' capacity to innovate (Vega-Jurado et al. 2008).

Previous research that measured the influence of external and internal factors (Oerlemans, Meeus, and Boekema 1998; Vega-Jurado et al. 2008) suggests patterns of a relationship between the external and internal determinants and companies' capacity to innovate, but they do not provide deeper insight into the determinants' robustness across different models and what the general supportive pattern of the determinants is. On the other hand, a Bayesian Model Averaging (BMA) approach measures the robustness of each determinant through the posterior inclusion probabilities (Sala-i-Martin, Doppelhofer, and Miller 2004). In particular, it shows the likelihood of each determinant to belong to the 'true' model. Thus, the contribution of this paper is that it will provide insight into the 'true' significance of the variables for CCI.

To achieve this aim, this paper will examine the robustness of explanatory determinants of companies' capacity to innovate. Particularly, we aim to answer what are the most robust determinants of companies' capacity to innovate. What is the relation between the robust determinants and companies' capacity to innovate? How can the results be used on a policy level to strengthen companies' capacity to innovate?

To answer these questions, panel data for a period of nine years for 135 countries was used from the yearly competitiveness reports of the World Economic Forum during the period of 2006/2007 to 2015/2016. Afterwards, the posterior inclusion probabilities (PIP) and posterior mean (Post Mean) were measured for each variable.

Determinants for innovation in the literature

Determinants internal and external to the organisation are related with the CCI (Vega-Jurado et al. 2008). By including determinants from both categories in our study, a more integral proposal for national and organisation policies can be developed (Damanpour 1991). However, in the literature the determinants are presented mainly through the national innovation capacity concept, as external determinants, and from a resource-based view, as internal determinants. Thus, here, we present and discuss the determinants identified in the literature of both camps.

National innovation capacity determinants

Since 2002, the national innovation capacity concept (Furman, Porter, and Stern 2002) has been the perceived centre point for evaluation of the countries' ability to realise innovation and identification of determinants that influence the innovativeness capacity. It comprises three building blocks: a common innovation infrastructure, an environment for innovation in a nation's industrial clusters, and the strength of linkages between these two (Furman, Porter, and Stern 2002). The determinants and their combinations can create environments that are most conducive to innovation realisation. This poses one central question for national innovativeness: what are the determinants that are identified in the literature?

To answer this question, we analysed papers that research some concept of national innovativeness (Appendix 1 includes a detailed overview per source). The aim is not to provide an in-depth analysis of the determinants used in the literature, but to present the generally used determinants for evaluation of national innovativeness. In this section we present a synthesis of the determinants identified in the literature.

The result is that there is a more narrow and wider inclusion of determinants.

The narrow research includes external determinants that are representative for the following domains (Feldman and Florida 1994; Patel and Pavitt 1994; Sternberg and Arndt 2001; Furman, Porter, and Stern 2002; Hu and Mathews 2008; Krammer 2009; Samara, Georgiadis, and Bakouros 2012):

- research domain, generally measured by determinants like R&D funding by government or private industry, R&D performed by universities or private industry, stock of international patents or patents applications, publication in academic journals;
- human domain, generally measured by population, GDP spent on higher education, employed S&T personnel, number of researchers, quality of scientific research institutions, work-force education and training, manufacturing employment, service sector employment;
- market domain, measured by gross domestic product, openness to international trade and investment, E-G concentration index, strength of venture capital markets, presence of business service providers, sales, technological intensity, trade intensity, foreign direct investments and cost of doing business;
- institutional domain, measured by strength of protection for intellectual property, stringency of anti-trust policies.

However, there are more as well as different types of external determinants that influence national innovativeness. Bartels et al. (2012) have identified 210 determinants that influence national innovativeness. Some of them are new ones like: cultural adaptability, robust juridical autonomy, trust in courts, political incoherence, policy incapacity, etc. The wider inclusion of determinants is in line with the research on reasons for failures of national innovativeness. In this direction, the determinants should not only relate to the market and structural system, but also to the transformational system, i.e. a system that deals with the strategic challenges of transforming systems of innovation, production and consumption (Weber, Matthias, and Rohracher 2012). Based on the identified type of failures and the identified mechanisms, we provide suggestions for additional domains and determinants that can be used as explanatory variables of national innovativeness.

- The infrastructure domain can be measured by the presence of physical and knowledge infrastructure. Determinants can relate from access to electricity, access to internet to access to scientific databases.
- The cultural domain can be measured by determinants that refer to political and socio-economic cultures, social norms and values. It should be noted that they are identified as soft institutional failures in Weber, Matthias, and Rohracher (2012), in contrast with the hard institutional failures, like regulations, standards, and legislation, which can hinder innovation. The determinants of hard institutional failures will be placed in the institutional domain.
- The interaction or network domain relates to linkages and integration between the entities. Explanatory variables, as cooperation with third parties in R&D (Vega-Jurado et al. 2008), relations between buyers and suppliers (Peters 2000), presence of clusters, and a network of funders (Porter and Stern 2001) can be used to evaluate the interaction domain.
- The direction domain can be measured by the presence of shared vision and portfolio of policy instruments.
- The demand domain covers the issues of demand and their influence on innovativeness. The determinants can be related to business/customer demand and government demand through public procurement.
- The policy coordination domain relates to horizontal and vertical coordination in the public sector, but also to the coordination between the public and private sector regarding the establishment and realisation of policies and how that cooperation is managed. In this domain the determinants can be related to the administrative capacity of the public sector.
- The reflexivity domain relates to the arrangements for societal discourse or more formalised discourse in parliamentary and ministerial environments. The determinants can be related to monitoring, anticipation, evaluation and impact assessment systems.
- The capabilities domain refers to the absence of the necessary capabilities to adapt to new and changing circumstances and (technological) opportunities (Weber, Matthias, and Rohracher 2012). The determinants should evaluate the ability of the firms to absorb new knowledge and innovate. These determinants draw from the resource-based view research.

Resource-based view determinants

The ability of the firm to absorb new knowledge and innovate builds on the resource-based view of the firm (Galende and de la Fuente 2003). According to RBV, the companies' capacity does not depend only on external or environmental factors, but also on internal factors and characteristics (Vega-Jurado et al. 2008). A considerable number of internal determinants have been evaluated as possible determinants of innovation (Vega-Jurado et al. 2008) (Appendix 2 includes a detailed overview per source). As a result, attempts were made to structure the internal determinants and provide a typology that can guide the identification and analysis of the determinants. Tidd (2000) proposed that there are strategic, organisational, market and technological competences. Within each of these groups, there are determinants that have an impact on companies' capacity to innovate. Damanpour (1991) has identified that these determinants are mainly composed of structural variables but also include process, resources and cultural variables. In this line, Crossan and Apaydin (2010) structure the determinants in three categories: leadership, managerial levers, and business processes. However, they have identified there is no overarching framework of innovation determinants that can cover the internal and external determinants of innovation (Crossan and Apaydin 2010) and identify their robustness.

Based on the previous discussion, the following conclusions can be made: (a) both the internal and external factors influence the companies' capacity to innovate; (b) a large number and different external and internal factors are used in the previous studies; and (c) widening of the base for the determinants of CCI should provide a more comprehensive model. Questions remain, however, about what the impact of different determinants is on the companies' capacity to innovate. As we develop our understanding of these determinants, we can identify how they can be transferred into meaningful suggestions for policy developments.

Data and method

To analyse the potential of a particular determinant in explaining the innovation capacity, we exploit the updated version of World Economic Forum's (WEF) Competitiveness dataset. This dataset spans from 2006/2007 to 2015/2016 and consists of over one hundred indicators which, when aggregated, measure the competitiveness of a country. For each period, most country-indicator scores are computed first by averaging individual scores from the Executive Opinion Survey (EOS), and then by combining them with the country-indicator scores from the previous EOS. EOS is a questionnaire conducted by WEF along the course of each year to capture the opinions of thousands business leaders in over one hundred countries about the competitiveness of their economy. Additionally, the Competitiveness dataset contains data from internationally recognised sources. A mutual characteristic of each observation is that it is normalised in such a way that it ranges from 1 to 7. For our purposes, we extract 62 country level continuous variables that were recognised as potential determinants, along with the innovation capacity of a country from WEF's database. Variable definitions are given in Appendix 3.

We focus on countries that have at least two observations for each indicator, as the data has to be time-demeaned in order to account for potential country-specific effects. Furthermore, we exclude an observation if there is missing data in it, as the Bayesian Model Averaging technique requires all models to be computed with the same observations regardless of which variables are included. This leaves us with an unbalanced panel of data covering 135 countries, 10 periods, and a total of 1.239 observations.

Statistical analysis (Bayesian model averaging)

In a formal setting, we assume that the innovation capacity y_{it} of a particular country i at time t is a result of a linear regression model M^m:

$$y_{it} = \alpha + X_{it}^{m\prime}\beta^m + \mu_i + u_{it} \tag{1}$$

where X_{it}^m is a $k_m \times 1$ dimensional vector of explanatory variables that determine the level of innovation capacity, β^m is the vector describing their marginal contributions, α the intercept of the regression, and u_{it} is the error term. In addition, we assume that the model includes μ_i, the unobserved country-specific factors that are relatively stable over time, such as geographical or cultural aspects.

A central question which then arises is the selection of the independent variables in M^m. While the literature review offers a comprehensive overview of all potential determinants, in reality we are never certain of their credibility. In order to circumvent the problem of choosing a model and potentially ending up with a wrong selection, we resort to the technique of Bayesian Model Averaging (BMA). BMA leverages Bayesian statistics to account for model uncertainty by estimating each possible model, and thus evaluating the posterior distribution of each parameter value and probability that a particular model is the correct one[1].

More precisely, the posterior probability for the parameters $g(\beta^m|y, M^m)$ is calculated using M^m as:

$$g(\beta^m|y, M^m) = \frac{f(y|\beta^m, M^m)g(\beta^m|M^m)}{f(y|M^m)} \tag{2}$$

From Moral-Benito (2015) it is clear that the posterior probability is proportional to $f(y|\beta^m, M^m)$ – the likelihood of seeing the data under model M^m with parameters β^m – and $g(\beta^m|M^m)$ – the prior distribution of the parameters included in the proposed model. By assuming a prior model probability $P(M^m)$ we can implement the same rule to evaluate the posterior probability that model M^m is the true one, as in:

$$P(M^m|y) = \frac{f(y|M^m)P(M^m)}{f(y)} = \frac{f(y|M^m)P(M^m)}{\sum_{n=1}^{2^K} f(y|M^n)P(M^n)} \tag{3}$$

The term $f(y|M^m)$ is called the marginal likelihood of the model and is used to compare different models to each other. The posterior model probability can also be written as:

$$P(M^m|y) = \frac{B_{m0}P(M^m)}{\sum_{n=1}^{2^K} B_{n0}P(M^n)} \tag{4}$$

where B_{m0} is the Bayes Factor between models M^m and the basic model M^0. In our case, this is the model including only country-specific effects.

With this setup, we can define the posterior distribution of β as a weighted average of the posterior distributions of β under each model using the posterior model probabilities as weights:

$$g(\beta|y) = \sum_{j=1}^{2^K} g(\beta|y, M^m)P(M^m|y) \tag{5}$$

Here, we are interested only in some parameters of the posterior distribution, such as the posterior mean and variance of each parameter. Using equation (S5) we can calculate the posterior mean as:

$$E(\beta|y) = \sum_{m=1}^{2^K} E(\beta|y, M^m)P(M^m|y) \tag{6}$$

Since the posterior mean is a point estimate of the average marginal contribution, we use it as our measure of the effect of the covariate on innovation capacity.

Another interesting statistic is the posterior inclusion probability PIP_h of a variable h, which measures the posterior probability that the variable is included in the 'true' model (Sala-i-Martin, Doppelhofer, and Miller 2004). Mathematically, PIP_h is defined as the sum of the posterior model probabilities for all of the models that include the variable:

$$PIP_h = P(\beta_h \neq 0) = \sum_{\beta_h \neq 0} P(M^m|y) \tag{7}$$

Posterior inclusion probabilities offer a more robust way of determining the effect of a variable in a model, as opposed to using p-values for determining statistical significance of a model coefficient because they incorporate the uncertainty of model selection. According to Equations (2) and (3), it is clear that we need to specify priors for the parameters of each model and for the model probability itself. To keep the model simple and easily implemented here we use the most often implemented priors. In other words, for the parameter space we elicit a prior on the error variance that is proportional to its inverse, $p(\sigma^2) \propto 1/\sigma^2$, and a uniform distribution on the intercept, $p(\alpha) \propto 1$, while the Zellner's g-prior (Zellner 1986) is used for the β^m parameters, and for the model space we utilise the Beta-Binomial prior (Ley and Steel 2009).

Results

Table 1 shows the results of the BMA estimates for the variables that are identified as 'significant'. Column (1) reports the posterior inclusion probability (PIP) of a variable in the growth regression. Additionally, we calculate the posterior mean (Column (2)) for each variable. Finally, in column (4) the sign certainty probability (SCP) is reported. SCP shows the posterior probability that conditional on a variable's inclusion a coefficient has the same sign as its posterior mean as reported in column (1). Value 1 indicates that in all the models the variable has a positive sign, while a value of 0 shows that in all the models the variable has a negative sign. The variables are sorted by their PIP and then by the posterior mean.

There are 27 variables that are identified as 'significant'. From the 27 identified variables 'significantly' related to CCI, 16 are positively related to the CCI (highlighted in light grey). For each of these variables the posterior mean coefficient is very precisely estimated to be positive. The sign certainty probability in column (4) shows that the probability mass of the density to the right of 0 equals 1. This means that in the models these variables have a significant and positive relation to the companies' capacity to innovate. Although eleven of these variables are included in all the PIP models, they can all robustly explain the changes in companies' capacity to innovate.

On the other hand, 11 variables (highlighted in dark grey) can robustly explain the changes in companies' capacity to innovate, but have a negative relation to that capacity. They have a negative posterior mean coefficient and the sign certainty probability in column (4) is 0, meaning that in all the models where the variables were included they had a negative relation to companies' capacity to innovate.

Discussion

We find that 27 from 62 variables used in the analysis can be said to have robust 'significant' relation to companies' capacity to innovate. These results are consistent even when eliciting different priors to

Table 1. Baseline estimation for 27 significant variables.

Determinant	PIP (1)	PM (2)	PSD (3)	SCP (4)
Value chain breadth	1	0.286	0.031	1
Production process sophistication	1	0.273	0.038	1
Venture capital availability	1	0.24	0.045	1
Company spending on R&D	1	0.239	0.039	1
Intensity of local competition	1	0.215	0.03	1
Foreign market size index	1	0.214	0.035	1
Quality of scientific research institutions	1	0.203	0.033	1
Extent of marketing	1	0.196	0.034	1
Efficacy of corporate boards	1	0.193	0.033	1
Internet access in schools	1	0.183	0.024	1
Willingness to delegate authority	1	0.159	0.03	1
Organised crime	1	−0.103	0.019	0
Prevalence of foreign ownership	1	−0.129	0.026	0
Government procurement of advanced tech products	1	−0.183	0.031	0
Local supplier quality	1	−0.312	0.044	0
Availability of latest technologies	0.998	−0.144	0.033	0
Reliance on professional management	0.996	−0.158	0.038	0
Cooperation in labour–employer relations	0.996	0.154	0.036	1
Availability of scientists and engineers	0.978	0.115	0.034	1
Ease of access to loans	0.941	−0.103	0.038	0
Prevalence of trade barriers	0.883	−0.071	0.033	0
Exports as a percentage of GDP	0.883	−0.003	0.001	0
Quality of the education system	0.813	−0.086	0.051	0
Effectiveness of anti-monopoly policy	0.755	−0.08	0.053	0
Mobile telephone subscriptions/100 pop.	0.736	0.001	0.001	1
Individuals using Internet, %	0.689	0.002	0.001	1
Favouritism in decisions of government officials	0.671	0.06	0.048	1

models space. Our results are in line with the Bartels et al. (2012) and Weber, Matthias, and Rohracher (2012) studies that there is large number of factors that are related to the companies' capacity to innovate (Appendix 4 contains selected citations that encompass the robust determinants). This impacts how the national innovation capacity should be shaped. Following their proposal, we will discuss the results of different variables clustered according to the domain to which they belong. The distribution of robust variables in different domain is presented in Table 2.

Capabilities domain

All the variables in the capabilities' domain have a PIP value of 1. This means that all of them robustly belong to the 'true' model. Furthermore, they have a strong positive relation with the companies' capacity to innovate. This is true for all the models where the respective variable has been used, as presented by the value of 1 in column (3) in Table 1. Hence, the significance of the internal variables has been confirmed for the development of companies' capacity to innovate. This is in line with the current literature that identifies the importance of the internal factors (Galende and González 1999; Galende and de la Fuente 2003; Caloghirou, Kastelli, and Tsakanikas 2004; Vega-Jurado et al. 2008). Furthermore, we can relate (Table 3) the robust variables with the 'basic competences' i.e. the organisational characteristics identified as possible determinants of innovation (Tidd 2000).

Hence, the identified variables need to be included when developing national policies and organisational strategies for development of companies' capacity to innovate.

Market domain

The results show a strong presence of the market variables. They have been robustly identified with the companies' capacity to innovate. Some variables have a PIP smaller than one, but they all show high posterior inclusion probability. The positive relation is present with the variables venture capital availability and intensity of local competition. This is in line with the existing literature (Porter and Stern 2001). Furthermore, the positive relation with foreign market size index resonates with the previous identification that there is a positive association between an orientation towards leading international markets and innovative performance (Romijn and Albaladejo 2002). On the other hand, the variable local supplier quality although identified as robust, has a negative relation with the companies' capacity to innovate. This is contrary to the results and suggestions made in the National Innovative Capacity concept (Porter and Stern 2001, 2002). Additionally, negatively related to companies' capacity to innovation is the prevalence of foreign ownership, exports as a percentage of GDP, ease of access to loans, and prevalence of trade barriers. Regarding the last one, it is needed to be explained that the prevalence of trade barrier (e.g. health and product standards, technical and labelling requirements, etc.) actually identifies that if there are less non-tariff barriers than the CCI will decrease. This might be related to the aspect that rising the standards will require the companies to develop the capacity to innovate to meet those standards. Additional research needs to be performed in order

Table 2. Distribution of robust determinants across domains.

Robust determinant	Domain
Value chain breadth	Capabilities
Production process sophistication	Capabilities
Extent of marketing	Capabilities
Efficacy of corporate boards	Capabilities
Willingness to delegate authority	Capabilities
Government procurement of advanced tech products	Demand
Reliance on professional management	Human
Availability of scientists and engineers	Human
Quality of the education system	Human

Table 3. Match between robust variables and competences.

Robust determinants	Competences
Value chain breadth	Strategic
Extent of marketing	Market
Production process sophistication	Technological
Willingness to delegate authority	Organisational
Efficacy of corporate boards	Organisational

to identify why the prevalence of foreign ownership, exports as a percentage of GDP, and ease of access to loans has a negative relation with the companies' capacity to innovate.

Research domain

The research domain variables are identified as robust with a positive relation to companies' capacity to innovate. This is in line with the existing literature. Regarding the R&D investments, it has been identified that they boost the innovativeness (Romijn and Albaladejo 2002) and it is a critical determinant of the level of realised innovation (Furman, Porter, and Stern 2002). The importance of the quality of scientific research institutions is also recognised in the literature, especially in the literature that promotes clusters (Porter and Stern 2001) and geography of innovation (Feldman and Florida 1994).

Infrastructure domain

The infrastructure domain shows that usage of internet for learning in schools has a robust and positive relation to companies' capacity to innovate. This includes mobile phone subscription and individuals using the internet. It shows that for the development of CCI, a wide presence of information and communication technologies is important. Differently from this conclusion, the previous research of innovation determinants has not included them. The reason for this might be that these technologies were not present in the periods that previous studies covered. Hence, further research that will include these variables needs to be performed.

In contrast, the variable availability of latest technology, although identified as robust, is negatively related to the companies' capacity to innovate. It means that the more the latest technologies are available, the more the capacity for innovation of the companies will decrease. This is contrary to the established opinion that the availability of the latest technologies has a positive effect on innovation. Further studies are needed to assess these relations.

Human domain

The availability of scientists and engineer's variable shows a robust and positive relation with the CCI. This is in line with the previous studies which include and identify the importance of the availability of scientists and engineers (Patel and Pavitt 1994). Hence, policies should be developed to support the creation of scientists and engineers.

Notwithstanding the previous, our results show a robust and negative relation between CCI and the quality of the education system. The relation is that the more the education system meets the needs of a competitive economy, the more the CCI will decrease. In the previous studies there is a tendency for the education to be recognised as important and positively related to innovation. However, there is a strong bias towards university education and university research (Freeman 1995). Our variable considers the complete educational system. This should be further explored, especially because education has a long-term influence.

Also, the variable reliance on professional management has a negative relation with CCI. Hence, having more professional management on the senior management positions, although chosen on the basis of merit and qualifications, decreases the CCI. This is contrary to the previous research where a positive relation has been found between professionalism and innovation (Damanpour 1991). Even in SMEs it has been identified that the best performing firms were significantly more likely to have introduced professional managers (Smallbone, Leig, and North 1995). However, this might be related to the type of strategic orientation of the companies (Aragón-Sánchez and Sánchez-Marín 2005; Fernández-Ortiz and Lombardo 2009). Thus, further research needs to be performed to explore this relation and provide additional explanation.

Institutional domain

Lack of favouritism in decisions of government officials has a robust and positive relation to the companies' capacity to innovate. Providing equal ground to each stakeholder is important. Thus, it provides an indication as to how the government should create their policies in order to support the development of companies' capacity to innovate. On the other hand, the CCI has a robust and negative relation with anti-monopoly policies. Further support to this result is previous studies where it has been identified that the anti-monopoly policies do not have a significant impact on innovation outputs (Furman, Porter, and Stern 2002). Another variable with a robust and negative relation to CCI is organised crime. The relation is that the companies' capacity will improve if there are more costs as a result of organised crime (mafia-oriented racketeering, extortion). In the absence of more detailed information, there is a need for additional research to explore this relation.

Interaction domain

If the labour–employer relations are generally cooperative, this is positively related to the companies' capacity to innovate. This variable has not been identified as such in the previous research of determinants for innovation. Thus, this provides an indication for extending the research on innovation determinants in this direction.

Demand domain

Our results show that if there is more government procurement that fosters innovation, then CCI will decrease. This result is different from the established notion about the public procurement of innovation. This is important because public procurement accounts for a large part of state spending. In the EU it accounts for more than 14% of GDP (European Commission) and in the USA the total government purchases amounted to $1.1 trillion (Pollin, Heintz, and Wicks-lim 2015). Furthermore, decisions to develop policies for public procurement of innovative solutions have been made in a number of countries, including the USA, Brazil, the Netherlands, the UK, Sweden, France, Norway, and Finland (European Commission). In particular, the EU has made strong steps towards the introduction of the public procurement of innovation (PPI) on a policy and operational level. The importance of PPI is underlined in the Europe 2020 flagship initiative Innovation Union.

Our result challenges the hypothesis that public procurement of innovation can improve the CCI and foster innovation. Our study suggests that it has a negative relation with the companies' capacity to innovate. We infer from this that there is a need for re-evaluation of countries' policies for public procurement of innovation. The starting point could be a debate about policy issues and mix that will consider a range of variables that support and enhance companies' capacity to innovate.

Non-robust variables

Our analysis for a number of variables provides little statistical support. Some of them are variables that in models presented in prior studies have been identified as important. For example, clusters have been identified as an important variable in the National Innovative Capacity Concept

(Furman, Porter, and Stern 2002), and as a variable that justifies the importance of the location (Porter and Stern 2001). Contrary to this, in our results the state of cluster development is not a robust variable and has very low PIP to be included in the 'true' model. Our result is in line with the result of Romijn and Albaladejo (2002).

Differently from the previous studies, our results show an apparent lack of robustness of the property rights variable. In the previous studies it has been identified that IP protection plays an extremely important role in R&D productivity (Furman, Porter, and Stern 2002). One reason for the difference might be that in the models of the previous studies the dependent (output) variable is the number of patents, which is closely related to the property rights. However, it should be acknowledged that there are calls for new approaches to innovation, like democratising innovation (Hippel 2005) or open innovation (Chesbrough 2003), which do not put strong emphasis on intellectual property. Furthermore, in a fast-technological development, what Patel and Pavitt (1994) have stated might be truer that 'innovative leads are maintained by accumulated investments in tacit knowledge rather than codified knowledge, so that intellectual property regimes are not therefore of central importance'.

Finally, the variable university-industry collaboration in R&D has very low inclusion probability and a mainly negative relation to the companies' capacity to innovate. This result goes against the results of the previous studies and existing policies. However, other studies (Vega-Jurado et al. 2008) have identified that the cooperation does not constitute a key factor in companies' innovativeness. Hence, there is a need to perform research to re-evaluate the positive relations identified in the literature. Furthermore, there might be a need for the policies to be focused more on developing the CCI than on relationships.

Conclusions

In conclusion, through the Bayesian Model Averaging approach we have identified 27 robust determinants of the companies' capacity to innovate. These variables are included in the 'true' model and can give a robust explanation to the changes in the CCI in the given period. Our results support the conclusion that the number of variables important for innovation are more diversified (Bartels et al. 2012) and that there is a need for a more holistic approach to support the CCI (Weber, Matthias, and Rohracher 2012).

Our results show a strong robustness and positive relation for capabilities determinants, suggesting that the internal (organisational) determinants have a prominent position in the 'true' model. This is in line with the current research on organisational determinants of innovation. Moreover, through this research we identify them as important when analysed with a large pool of external determinants. Thus, we conclude that future research and policy development needs to jointly consider the internal and external determinants of companies' capacity to innovate.

Our analysis does not support the inclusion of many variables found in prior innovation studies and suggests that the statistical importance of the main focus variables in many prior studies (like clusters, intellectual property, and university-industry collaboration) are not robust in a much wider set of determinants. Furthermore, the results identified that some variables, like the public procurement for innovation and effectiveness of anti-monopoly policies, have a negative relation to innovation.

These findings imply that innovation policies, managerial practices and scientific research may be improved by integral consideration of internal and external determinants. On a policy level, a finding that should be of particular interest to policy makers is that determinants, like public procurement for innovation and clusters, are not robust determinants of CCI. Hence, whereas future research is needed, it is conceivable that there is a need to re-evaluate the national policies to support innovation. In this direction, we assume that the direct financial support by the governments to supplement the private R&D will improve the companies' capacity to innovate. Thus moving from fostering public procurement for innovation to providing public funding for innovation. On an organisational level we demonstrate which organisational competences are robust determinants in a 'true' model. This provides a direction for the management as to which competences are to be developed within the organisation. Finally, from a scientific research perspective, at the very least, our results suggest that an integral approach including internal and external determinants can play a larger role in explaining the companies' capacity to innovate. Thus, future research should define empirical measures that would permit a more adequate operationalisation of the 'true' model and the variables identified in this study.

A possible limitation of our study may be the fact that we focus on deriving global conclusions, rather than emphasising the determinants of innovation capacity in a particular region or country. Definitely, the innovation capacity of countries/regions with a distinguishing level of economic development should be driven by different variables. Nevertheless, we point out that while our study offers a principled way for inferring general properties, it can also be easily reduced to such an analysis.

Note

1. We note that, in general there are possible 2^K models, where K is the number of potential determinants. In our case, we estimate a total of 2^{62} models.

Disclosure statement

No potential conflict of interest was reported by the authors.

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